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Setting the carbon footprint criteria for public construction projects

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Abstract

This paper describes a method for controlling the growth of the carbon footprint of buildings during the preparation, design and procurement stages of construction projects. The process utilizes prevailing cost estimation techniques. As an outcome, new indicators for *carbon efficiency* and *carbon economy* of buildings are proposed. They have been developed together with the city of Espoo in a research project that included carbon footprinting of existing buildings and arranging an architectural competition for a low-carbon public building. Both carbon efficiency and economy seem to offer flexible opportunities for an integrated comparison of the environmental and economic sustainability of buildings.

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1. Introduction

1.1. The relevance of carbon footprinting of public buildings

The Nordic Built Charter (2012) - signed by more than 120 cities, companies and organizations - states 10 principles for the future built environment. Among these is "zero carbon emissions over the full lifecycle" of a building. Indeed, drastic reductions in anthropogenic greenhouse gas (GHG) emissions are required if we wish to avoid the severe risks (Hansen et al. 2013) that may follow anthropogenic climate change.

As we move towards nearly zero energy buildings, nZEBs (European Parliament, 2010), we need to widen our perspective from the emissions of operational energy use. After all, new buildings will reach nZEB class by 2020; the dominance of emissions seems to change. The relative dominance of the use phase - lifecycle module B6

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according to standard EN15643-2 (CEN, 2011) - of the building seems to decrease and the impact from the material production phase (lifecycle modules A1-3) seems to increase (Hafner et al. 2013). This trend is reinforced by the decreasing carbon intensity of energy (IPCC, 2014), although some studies have found that the decarbonization of energy may slow down in the future (IEA, 2014).

Material selection may change the carbon footprint of energy efficient buildings considerably (Kuittinen, 2013). It has also been found that alternative construction materials may lead into greatly differing weights of building parts thus influencing the emissions of the complete building (Pasanen, 2011). Thus there is a growing need for developing methods for estimating and managing the accumulation of carbon footprint throughout the full lifecycle of the building.

1.2. New approaches needed

In design work, there will likely be needs for estimating the dominance of emissions associated with the lifecycle stages of a building, especially in the production and operation phases. The design process of a building today can benefit from energy simulation tools that allow the architect to simulate how iterative changes affect the energy performance of a building. A similarly practical and widespread method is not, however, used for tracking the carbon footprint of construction products. Several BIM-based (VTT, 2013; Liukka 2014) and standalone (VTT 2013, Finnish Environment Institute 2013, Bionova 2014) estimation tools have been developed, but they have failed to gaining wider use. This is partly due to the legal need to calculate the energy certificate for buildings (Ministry of the Environment 2013) while no requirement for calculating the carbon footprint exists.

Yet, environmental assessment interventions may have considerable impact on the carbon footprint of a building. For instance, the design of the new office for WWF in Woking, UK, included environmental assessment for minimizing the GHG emissions. Lowenstein (2014) found that during and after the design phases the carbon footprint of the building could be reduced from 16.510 to 10.920 t CO₂e. This improvement was the result of comprehensive lifecycle assessment and iterative comparison of alternative technical solutions.

From an economic perspective there exists the need for optimizing the payback times of investments that are needed for nZEB's both in terms of money and GHG emissions. For example, Becchio et al. (2014) found out that the global cost of nZEB solutions is still (in 2014) from 212 to 313 €/m² more expensive than standard solutions. Liu et al. (2014) discovered that if only incremental economic benefits of energy efficiency applications are observed, sustainable buildings seem to have poor potential for market investments. However, it will be considerably more expensive to postpone the mitigation of climate change than to take action now (World Bank, 2012).

1.3. Green public procurement yet to reach its potential

The revision of the EU's procurement directive (European Parliament, 2014) aims at "facilitating a better integration of environmental considerations in procurement procedures" (European Commission, 2014). Based on the revision of the directive, public purchasers can now decide to choose the product or service based solely on its environmental performance. Therefore the public procurement of construction products requires reliable and transparent practices for rewarding the least harmful environmental impact of the purchased product or service.

However, difficulties have been reported in the recent implementation of green public procurement (GPP) criteria. For example, Alhola (2012) discovered that Finnish public procurers have not known how stringent environmental criteria can be demanded and therefore the criteria have been set low. Sporrang and Bröchner (2009) found out that only 30% of Swedish municipalities used environmental awarding criteria when purchasing design services. Of them, almost 40% reported difficulties in the awarding of the environmental criteria of design services. To unleash the potential of the revised directive, procurers need practical instruction for setting the GPP criteria of building products and design services.

Life cycle assessment (LCA) has been proposed as the most comprehensive means for environmental awarding of different products in GPP (European Commission, 2014b). However, this may, in many cases, require an external

LCA consultant and thus make the procurement process longer. Today, the calculation of the carbon footprint of buildings is still a specialty. It is not commonly carried out in public or private building projects, apart from pioneering building projects or architectural competitions.

2. Materials and methods

2.1. Collaboration with the city of Espoo

Because of steady population growth in Espoo, the second largest city in Finland, there is constant demand for new kindergartens and schools. The city aimed at implementing its climate action plan (Espoo, 2011) while developing a concept for new kindergartens. The project was carried out with Aalto University, which is located in the same city, and aimed at development of a simplified carbon footprint management method for the city's building department. Intermediate goals included arranging tutored design competition for a new low-carbon kindergarten project, calculating the carbon footprint of the city's existing public buildings and assessing the m²-based carbon footprint of typical structure types that are used in public buildings.

2.2. Calculation of the carbon footprint of existing public buildings in Espoo

Three recently built kindergartens and one school were carefully analyzed. The carbon footprint from the production phase of their construction materials was calculated according to standards EN15978 (CEN, 2011b) and EN15804 (CEN, 2014) using ICE2011 dataset (University of Bath, 2011). In addition to the emissions, also biogenic carbon storage of wood-based construction materials was calculated according to standards EN16449 (CEN, 2014b) and EN16485 (CEN, 2014c). Inventory was based on the exhaustive bills of the quantities from the procurement phase of each project. Structural details were checked within construction drawings and by interviewing structural designers and project managers. The exclusion of other lifecycle phases than A1-3 was made based on the hypothesis that lifecycle modules B6 (operative energy use) and A1-3 (production) have been found to be the dominant for the accumulation of GHG emissions, as described in chapter 1. Building service components were excluded, as they are not listed in the structural cost estimation documentation and there is generally no information for their environmental impact in data sets. In future studies it would also be important to include their GHG emissions, as they may in some cases be significant (Lowenstein, 2014).

2.3. Workshops for promoting carbon footprinting through an architectural design competition

The aim of the competition was to design the concept of low-carbon an energy-efficient kindergarten for the city of Espoo. The assignment included the design of buildings, their energy concept, parks and playgrounds as well as the immediate infrastructure of the development. Five teams were selected for the competition, each consisting of architects, landscape architects, structural engineers, energy consultants and infrastructure planners. To ensure that each team would have the same starting level for designing low-carbon buildings, a series of lectures and workshops was arranged by Aalto University. The workshops were followed by the actual design competition. After the competition entries were handed in, carbon footprint estimations were done for the buildings and for the park, including the carbon sequestration of urban trees. Calculation results were given to the jury.

3. Results

3.1. Current level of carbon footprint in public buildings

Calculation results are divided into GHG emissions (graph 1) and biogenic carbon storage (graph 2). Results are broken down into building parts according to the classification commonly used in cost estimates.

The results reveal the *importance of using a proper functional unit* for the assessment. For ground works, foundation and exterior structures (building part categories if Fig.1 and 2) a relevant functional unit seems to be 1m^2 of site area. The amount and type of ground work is directly related to the area and soil condition of the site. Likewise, the foundation type is dependent on the soil type, although the selected structural system has an influence as well. However, from the viewpoint of allocating emissions, it can be argued that foundation-related emissions are more subject to the particular site in question.

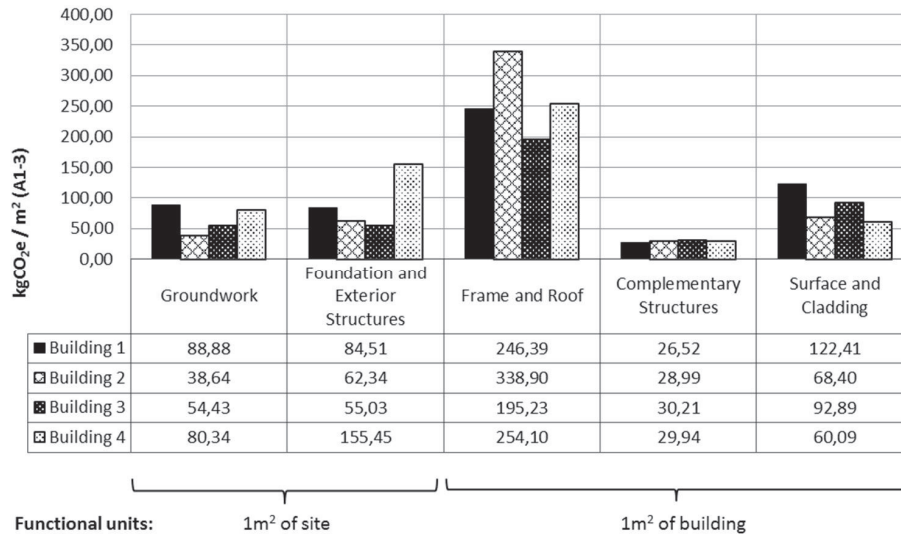


Fig 1. GHG emissions from the production phase of the case study buildings.

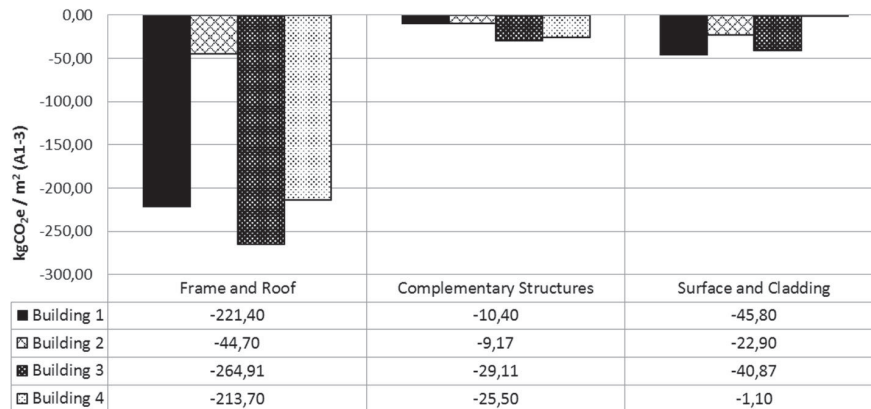


Fig 2. Biogenic carbon storage of the wooden parts during the production phase of the case study buildings.

For structural parts that are directly related to the building (categories 3-5 of Fig. 1), 1m^2 of buildings' gross area seems to be the relevant unit. If gross- m^2 -based functional unit would be used for e.g. ground works, the results

would not describe the amount of emissions that are caused by different sizes of the sites. Similarly, if the site area-based functional unit would be used for describing emissions caused by structures of the building, the results would be distorted as the area of the site and of the building have no influence on each other in terms of GHG emissions.

The carbon footprint calculations also reveal that in some cases the biogenic carbon storage of wooden building parts in the frame and roof may lead to significant emission savings during the production phase of the building (graph 2). It has to be noted, however, that the same savings are to be amortized over the full lifecycle of wood-based construction products following the corresponding flows of biogenic carbon (see EN16485, chapter 6.3.4.2). Still, as wood-framed buildings are lighter per m² than the corresponding concrete-framed buildings, lower average emissions may be achieved.

3.2. Tutored carbon footprinting can improve the results of an architectural competition

The experience from the tutored design competition of a kindergarten in Espoo proved that with a moderate intervention – workshops and lectures – it seems to be possible to influence low carbon design. Some entries included novel ideas for minimizing the carbon footprint of the buildings. One of the entries demonstrated the potential of optimal landscape architecture: the carbon uptake of planted park trees during 50 years was equal to the emissions from the production of construction materials of the buildings on the same site. The experience proved that universities and research institutes can help cities to implement their climate strategies into public building projects.

The selected kindergarten concept did not perform best in terms of carbon footprint or energy efficiency. However, they were not the only criteria. The integration of carbon footprinting into the multi-criteria awarding process can be considered as a new viewpoint to the decision makers. Therefore it has potential for infiltrating gradually into forthcoming building projects.

3.3. Development of a simplified assessment method for the city of Espoo

The observations from the tutored design competition and the findings from the carbon footprinting of existing buildings were used for developing a method for managing the carbon footprint of buildings during their design stage. The method consists of development of design reference values in the form of a catalogue of typical structure types including their m²-based carbon footprint and costs. These reference structures can be used in the preliminary planning phase of a building.

Below-ground construction materials and external materials (for, e.g., fencing, parking lots and playground structures) vary greatly depending on the size of the site and its soil conditions (see graph 1). Therefore, especially in the preliminary planning phase, it is more relevant to tackle the emissions that can be altered rather than taking the burden of estimating the carbon footprint of building parts that are closely related to the given site. However, it would be very important to tackle the climate impacts of the latter as well, when it comes to city planning and site selection.

4. Conclusions: Introducing carbon efficiency and carbon economy

4.1. Carbon efficiency is the ratio of embodied GHG emissions and operative energy use

The main finding is in the cross-comparison of GHG emissions, energy demand and construction costs of the case study buildings. The ratio of these indicators may be more important than observing any of them separately. Instead, a flexible method for optimizing the “carbon efficiency” of the building could be used. It can be defined by utilizing the information from existing documents that are usually required in the building permit application.

Carbon efficiency is derived from the output of GHG emissions from the production phase of the building and operative energy demand (E-value). Carbon stored in wooden parts is not included in the equation, as it will be released back into the atmosphere in the end-of-life stage.

Formula 1: Carbon efficiency and carbon economy of buildings.

$$\text{Carbon efficiency} = \frac{C \times E}{1000}$$

$$\text{Carbon economy} = (C \times E \times \text{€}) 10^{-7}$$

where C = GHG emissions from production phase (kgCO₂e/m²),
 and E = Operative energy demand (kWh/m²/a),
 and € = Construction costs (EUR/m²).

Traditionally, efficiency (r) is understood to be the ratio of desired output (P) to inputs (C): $r=P/C$. The greater the number, the greater the efficiency. In our case we have chosen to aim at low figures by multiplying the factors instead of dividing them, as shown in formula 1. This way the outcome is understandable in comparison to other environmental performance factors – such as energy efficiency and carbon footprint – which are lower the better the performance gets. For ease of use, the digits have also been modified.

Carbon efficiency enables case-specific flexibility for the design and operation of the building. Efficiency is improved if carbon footprint of the construction products is lowered. Alternatively, efficiency can be improved by lowering the energy demand of the building. This enables designers and project managers to find out the most feasible way of reaching climate-conscious solutions.

Public building projects are different from each other. For example, soil conditions may lead to extensive stabilization or piling. This will give the building frame a large carbon footprint regardless of above-ground material choices. Available energy mix, on the other hand, may be carbon-intensive or it may not be possible to utilize on-site energy. In such case the operative energy use GHG emissions will grow and burden the buildings' lifecycle carbon footprint.

Furthermore, by including carbon efficiency into sustainability assessment, the lifecycle coverage is broadened. Ideally, the full lifecycle should be studied. However, in typical public building projects, such a comprehensive analysis may often be too demanding. Therefore carbon efficiency is a realistic step towards full lifecycle assessment.

4.2. Carbon economy and other cost-related indicators

In addition to optimizing carbon efficiency as described above, the relation of construction costs and lifecycle carbon footprint can be optimized for better “carbon economy” of public buildings. This is done by simply multiplying the m²-based GHG emissions and operative energy use with construction costs.

In addition to carbon economy there are several other cost-related indicators that may be worth studying. For instance, the ratio of carbon efficiency and lifecycle costs of the building gives information about the economic and environmental performance of the life cycle of the studied building. The ratio of operative energy demand to construction costs informs decision makers how soon the investments that are made for the improvement of energy efficiency can be amortized via savings of operative energy use, given that the price trend of energy can be reliably

Table 1: Exemplary calculations of the carbon efficiency of case study buildings. Lower values indicate better performance. Building 4 has the second lowest carbon footprint but clearly the best energy efficiency, being a passive house. Therefore it has the best overall carbon efficiency and carbon economy. Building 3 has the lowest carbon footprint, but the weakest energy efficiency, thus not scoring well.

	<i>Building 1</i>	<i>Building 2</i>	<i>Building 3</i>	<i>Building 4</i>
Gross building area m ²	1288,00	10546,00	498,50	1475,00
Carbon footprint (above ground, A1-3) kgCO ₂ e/m ²	395,32	436,29	317,37	348,79
Operative energy use kWh/m ² /a	168,00	119,00	242,00	94,00
Construction cost EUR/m ²	3504,84	2996,21	3011,38	4152,08
Carbon efficiency	66,41	51,92	76,80	32,79
Carbon economy	23,28	15,56	23,13	13,61

defined. Together with the optimization of buildings life cycle costs, carbon economy may improve the environmental comprehensiveness of economic decision making in public building projects.

4.3. Setting the system boundaries for carbon footprinting in public building projects

Defining clear and understandable criteria for GPP awarding has proved to be challenging (see chapter 1.3). EN standards have been proposed in the GPP guidebooks for criteria setting. Standard EN15978 states that the system boundary for environmental assessment of buildings shall include the entire building and site, including temporary structures and scaffolding. Based on the findings of this study it can be argued, however, that the system boundary for GPP criteria setting should be limited to only frame and roofing, complementary structures and claddings (categories 3-5 of graph 1).

Using such boundary would make it considerably easier to compare which of the offered structural solutions has the least GHG emissions on the given site. Furthermore, this practical system boundary would also enable construction companies to use environmental product declarations for their building products or buildings without having to assess the environmental burdens associated with construction conditions on each site. However, environmental impacts for groundwork, landscaping and external structures should be assessed separately.

By making a division on the carbon footprinting of building and site, it would be possible to propose that the busy building permission authorities and project managers could take the essential step into the world of carbon footprinting in public building projects.

5. Summary

This study has shown how existing documentation methods can be utilized for defining the carbon footprint of construction materials in different phases of a design and construction project. The existing processes of cost estimation provide valuable data for this definition.

The proposed new indicators, carbon efficiency and carbon economy, are steps forward in the evolution of climate-conscious buildings. First, they introduce the carbon footprint of construction materials as an elemental part of a building's sustainability assessment. Secondly, they enable flexible strategies to reach good carbon efficiency and are thus suitable to different contexts. Thirdly, they help to describe the economic dimension of sustainable construction.

To reach these indicators, it is important to set the functional units of comparison right. As described in this study, the area of the site can be used as functional units for the carbon footprinting of groundwork and foundations, whereas the area of the building is the appropriate functional unit for carbon footprinting of structural parts of the building.

Furthermore, it could be observed that modest interventions to design work of public buildings help to mitigate GHG emissions. Especially in architectural competitions, focused seminars and tutoring can improve the environmental quality of design.

Finally, widening the sustainability assessment of public buildings by introducing carbon efficiency does not require major changes in design processes. It only requires cross-comparison of data that is already being documented. Optimization of carbon efficiency may significantly deepen the understanding of the interdependence of energy and material use in buildings. This enables designers and authorities to improve the environmental and economic sustainability of our built environment.

In order to reach ambitious climate goals – such as described in the Nordic Built Charter – more than incremental changes are needed. Carbon efficiency and carbon economy should be tested in the public construction sector so that their potential in mitigating the GHG emissions of the construction sector can be quantified and taken into practice.

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References

- Alhola K. Environmental criteria in public procurement - Focus on tender documents. In *Monographs of the Boreal Environment Research No 40*; 2012.
- Becchio C, Dabbene P, Fabrizio E, Monetti V and Filippi M. Cost optimality assessment of a single family house: Building and technical system solutions for the nZEB target. *Energy and Buildings* 2014; 90:173-187.
- Bionova Ltd. 360 Optimi environmental assessment tool. More information online: <http://www.360optimi.com/en/home>, accessed 30.11.2014.
- Bruckner T., I. A. Bashmakov, Y. Mulugetta, H. Chum, A. de la Vega Navarro, J. Edmonds, A. Faaij, B. Fungtammasan, A. Garg, E. Hertwich, D. Honnery, D. Infield, M. Kainuma, S. Khennas, S. Kim, H. B. Nimir, K. Riahi, N. Strachan, R. Wiser, and X. Zhang, 2014: Energy Systems. In: *Climate Change 2014: Mitigation of Climate Change. Contribution of Working Group III to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change* [Edenhofer, O., R. Pichs-Madruga, Y. Sokona, E. Farahani, S. Kadner, K. Seyboth, A. Adler, I. Baum, S. Brunner, P. Eickemeier, B. Kriemann, J. Savolainen, S. Schlömer, C. von Stechow, T. Zwickel and J.C. Minx (eds.)]. Cambridge University Press, Cambridge, United Kingdom and New York, NY, USA.
- CEN European Committee for Standardization. EN 15643-2:2011. Sustainability of construction works. Assessment of buildings. Framework for the assessment of environmental performance; 2011.
- CEN European Committee for Standardization. EN 15978:2011. Sustainability of construction works: Assessment of environmental performance of buildings – Calculation method; 2011.
- CEN European Committee for Standardization. EN 15804:2014. Sustainability of construction works – Environmental product declarations – Core rules for the product category of construction products; 2014.
- CEN European Committee for Standardization. EN 16449:2014. Wood and wood-based products. Calculation of the biogenic carbon content of wood and conversion to carbon dioxide; 2014.
- CEN European Committee for Standardization. EN 16485:2014. Round and sawn timber – Product category rules for wood and wood-based products for use in construction; 2014.
- City of Espoo. Pääkaupunkiseudun ilmastostrategia 2030. Espoon toimenpideohjelma 2011 (In Finnish: Climate strategy of the capital region 2030. Action plan for the City of Espoo). Available online: <http://espoo04.hosting.documenta.fi/kokous/2011200163-9-1.PDF>, accessed 11.11.2014.
- Directive 2010/31/EU of the European Parliament and of the Council of 19 May 2010 on the energy performance of buildings (recast).
- Directive 2014/24/EU of the European Parliament and of the Council of 26 February 2014 on public procurement and repealing Directive 2004/18/EC.
- European Commission. Public procurement reform. Factsheet No. 7: Green Public Procurement; 2014. Available online: http://ec.europa.eu/internal_market/publicprocurement/docs/modernising_rules/reform/fact-sheets/fact-sheet-13-concession-award-criteria_en.pdf, accessed 11.11.2014.
- European Commission Green Public Procurement Training Toolkit - Module 3: Purchasing Recommendations 2009. Available online: http://ec.europa.eu/environment/gpp/eu_gpp_criteria_en.htm, accessed 30.11.2014.
- Finnish Environment Institute. SYNERGY Carbon Footprint Tool; 2013. Available online: http://www.syke.fi/en-US/Research_Development/Consumption_and_production_and_sustainable_use_of_natural_resources/Calculators/Synergy, accessed 28.11.2014.
- Hafner A et al. Good practices for carbon efficiency in wood construction. In: Kuittinen M et al., editors. *Wood in Carbon Efficient Construction*, Brussels: CEI-Bois; 2013, p.72-75.
- Hansen J et al. Assessing "Dangerous Climate Change": Required Reduction of Carbon Emissions to Protect Young People, Future Generations and Nature. *PLOS ONE* 2013; 8:26.
- International Energy Agency (IEA). Tracking Clean Energy Progress. Available online: http://www.iea.org/publications/freepublications/publication/Tracking_clean_energy_progress_2014.pdf, accessed 30.11.2014.
- Kuittinen M. Tervakukka Passive House. In: Kuittinen M et al., editors. *Wood in Carbon Efficient Construction*, Brussels: CEI-Bois; 2013, p.142-45.
- Liu Y, Guo X and Hu F. Cost-benefit analysis on green building energy efficiency technology application: A case in China. *Energy and Buildings* 2014; 82:37-46.
- Liukka M. Rakennusmateriaalien hiilijalanjäljen tietomallintaminen. (In Finnish; Building information modelling and carbon footprint of construction materials). Espoo: Aalto-yliopiston arkkitehtuurin laitos; 2014.
- Lowenstein O. Office building in Woking. Eco-Tech revisited. *Detail Green* 2014(2), p.28-33.
- Ministry of the Environment. Laki rakennuksen energiatodistuksesta (In Finnish; Law on the energy certificate of a building), Available online <http://www.finlex.fi/fi/laki/alkup/2013/20130050>, accessed 30.11.2014.
- Nordic Innovation. The Nordic Charter. Available online: <http://www.nordicinnovation.org/fi/nordicbuilt/thenordic-built-charter/>, accessed 30.06.2014.
- Pasanen et al. Passiivitalon asuinkerrostalon elinkaaren hiilijalanjälki. Tapaustutkimus kerrostalon ilmastovaikutuksista. (In Finnish; Lifecycle carbon footprint of a passive-level residential block of flats. A case study of the climate impacts of a block of flats.) *Sitran selvityksiä* 63 2011; p.14.
- Sporrong J and Bröchner J. Public Procurement Incentives for Sustainable Design Services: Swedish Experiences. *Architectural Engineering and Design Management* 2009; 5:12.
- University of Bath, Sustainable Energy Research Team (SERT), 2011. Inventory of Carbon and Energy (ICE), version 2. Available at: <http://www.bath.ac.uk/mech-eng/research/sert/>. Retrieved 14.05.2014.
- VTT Technical Research Centre. ILMARI Calculator for assessing the carbon footprint of construction materials. Description available online in Finnish: http://www.vtt.fi/news/2013/ilmari-laskuri_rakennusmateriaalien_hiilijalanjaljen_arvioimiseen.jsp, accessed 30.11.2014.
- VTT Technical Research Centre. The €CO2 Wood House Calculator; 2013. Available online: www.eco2wood.com, accessed 28.11.2014.
- World Bank. Turn Down the heat: Why a 4°C warmer world must be avoided. Washington DC: World Bank; 2012.